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(54) Title: CROSS-LINKED HYALURONIC ACID-LAMININ GELS AND USE THEREOF IN CELL CULTURE AND MEDICAL IMPLANTS

(57) Abstract: The present invention concerns universal biocompatible matrices comprising cross-linked hyaluronic acid-laminin gels useful for clinical applications including as implants, for tissue engineering as well as in biotechnology. The gel matrices according to the present invention may be used clinically either per se or as a cell bearing implant. The gels are particularly useful for use for transplantation to the nervous system or as a coating or a scaffold for use on medical devices including stents.

**CROSS-LINKED HYALURONIC ACID-LAMININ GELS AND
USE THEREOF IN CELL CULTURE AND MEDICAL IMPLANTS**

Field of the Invention

5 The present invention concerns universal biocompatible matrices comprising cross-linked hyaluronic acid-laminin gels, processes of making these gels and uses thereof for clinical applications including as implants for guided tissue regeneration, tissue engineering and for coating of medical devices, as well as in biotechnology.

10

Background of the Invention

15 The ability to induce and guide tissue regeneration is an unmet medical need, particularly in systems such as the central nervous system and the cardiovascular system where loss of function results in severe debilitation or death.

20 Neuronal cell death as a result of injury, ischemia or degeneration within the central nervous system (CNS) is generally considered irreversible. Nerve regeneration is largely considered an unattainable goal within the CNS, due to the inability of these cell types to multiply after maturation of the brain, which occurs early in life. Axonal injury within the central nervous system is also generally thought to be irreversible when it involves severance of the axons. Various reports of success in nerve regeneration in animal models have not yet led to any satisfactory therapeutic approach to this problem, though it is envisaged that implants or transplants containing viable neurons or their progenitors, possibly

derived from human embryonic stem cells, may one day provide an option for attaining CNS regeneration.

The cardiac muscle and cardiovascular system are largely considered to be incapable of regenerating their original structure following myocardial infarct, and 5 therefore arterial occlusion in the heart results in irreparable damage to the cardiac muscle function. One of the therapeutic approaches taken to overcome this pathological phenomenon is the deployment of medical devices called stents to prevent coronary and other vascular system occlusion, though these devices often result in secondary restenosis, due to injury to the endothelial cell layer during 10 introduction of the stent itself.

It is envisaged that these and other major medical problems might be resolved if the implants, transplants or medical devices were provided with a biocompatible scaffold or coating that would enable their integration into the damaged area without evoking secondary damage. Thus, an intracoronary stent 15 may be coated with a biocompatible matrix that would prevent it from eliciting restenosis, or cell bearing medical implants for the CNS might be endowed with the mechanical and biochemical properties that would enable it to survive and propagate as needed.

The attributes of an ideal biocompatible matrix would include the ability to 20 support cell growth either in-vitro and in-vivo, the ability to support the growth of a wide variety of cell types or lineages, the ability to be endowed with varying degrees of flexibility or rigidity required, the ability to have varying degrees of biodegradability, the ability to be introduced into the intended site in vivo without provoking secondary damage, and the ability to serve as a vehicle or reservoir for

delivery of drugs or bioactive substances to the desired site of action.

Matrices useful for guided tissue regeneration and/or as biocompatible surfaces useful for tissue culture are well known in the art. These matrices may therefore be considered as substrates for cell growth either in vitro or in vivo.

5 Suitable matrices for tissue growth and/or regeneration include both biodegradable and biostable entities. Among the many candidates that may serve as useful matrices claimed to support tissue growth or regeneration, are included gels, foams, sheets, and numerous porous particulate structures of different forms and shapes.

10 In many instances the matrix may advantageously be composed of biopolymers, including polypeptides or proteins, as well as various polysaccharides, including proteoglycans and the like. In addition, these biopolymers may be either selected or manipulated in ways that affect their physico-chemical properties. For example biopolymers may be cross-linked either 15 enzymatically, chemically or by other means, thereby providing greater or lesser degrees of rigidity or susceptibility to degradation.

Among the manifold natural polymers which have been disclosed to be useful for tissue engineering or culture, one can enumerate various constituents of the extracellular matrix including fibronectin, various types of collagen, and 20 laminin, as well as keratin, fibrin and fibrinogen, hyaluronic acid, heparan sulfate, chondroitin sulfate and others.

US patents 5,955,438 and 4,971,954 disclose collagen-based matrices cross-linked by sugars, useful for tissue regeneration.

US patent 5,948,429 disclosing methods of making and using biopolymer

foams comprising extracellular matrix particulates.

US 6,083,383 and 5,411,885 disclose fibrin or fibrinogen glue and methods for using same. US 5,279, 825 and 5,173,295 disclose a method of enhancing the regeneration of injured nerves and adhesive pharmaceutical 5 formulations comprising fibrin. US 4,642,120 discloses the use of fibrin or fibrinogen glue in promoting repair of defects of cartilage and bone.

US patents 6,124,265 and 6,110,487 disclose methods of making and cross-linking keratin-based films and sheets and of making porous keratin scaffolds and products of same.

10 Hyaluronic acid (HA) is a naturally occurring high molecular weight polymer belonging to the glycosaminoglycan family, composed of repeating units of glucuronic acid and N-acetyl glucosamine. HA readily forms hydrated gels which serve *in vivo* as space filling substance. The utility of hyaluronic acid as a beneficial component for supporting tissue growth is well established in the art, as 15 exemplified in US 5,942,499, which discloses methods of promoting bone growth with hyaluronic acid and growth factors. US 5,128,326 and 5,783,691 disclose methods of producing and using cross-linked hyaluronans in promoting tissue repair and as reservoirs for bioactive agents including drugs or growth factors

20 Laminin (LN) is an adhesive glycoprotein of high molecular weight, which is known as a major cell matrix binding component. US patents 4,829,000 and 5,158,874 exemplify uses of gels or matrices comprising laminin.

International patent application PCT/IL99/00257 of Shahar et al. (published as WO 99/58042) discloses methods of ameliorating impairments of the central nervous system by culturing neural tissue on a matrix gel composed of

hyaluronic acid and laminin. It was previously reported that the combination of HA and LN provides both a flexible elastic bonding and tight rigid bonding cell matrix. Goldman et al. (Ann. N.Y. Acad. Sci. 835, 30-55, 1997) disclosed certain preliminary results using this technique, without providing any details or methods 5 for obtaining these gels.

Nowhere in the background art is it taught or suggested that matrices of hyaluronic acid and laminin are useful for clinical applications *in vivo*, or that such gels are useful for culture with non-neuronal cell types. Furthermore, the use of these combined HA-LN matrices as a coating for medical devices or in an 10 implant suitable for transplantation has never been disclosed, nor has the use of cross-linking agents to provide stabilization of the gels.

Summary of the Invention

It is an object of the present invention to provide a universal matrix, which 15 is biocompatible and affords a convenient environment for cell attachment, growth, differentiation and tissue repair. It is a further object of the present invention to provide a matrix suitable for many different cell types and which may conveniently be used either *in vitro* or *in vivo*. It is a further object of the present invention to provide a gel matrix useful for clinical applications due to its unique 20 attributes of fostering tissue regeneration. It is yet a further object of the present invention to provide a gel matrix which is useful for clinical applications due to its unique attributes of elasticity and malleability, enabling the use of the gel both for injection into a cavity or as a coating for a medical device or scaffold.

These and other objects of the present invention are met by matrix gels

comprising Hyaluronic Acid combined with Laminin, designated herein as HA-LN gels. The laminin component stabilizes the cells, provides cell attachment sites and improves cell viability, particularly of cells that are intended for use in tissue regeneration. However, laminin on its own suffers from the drawback that its 5 physical characteristics are inappropriate for use in an implant. The HA component provides the physical attributes that are required to enable the laminin to fulfill its purpose. The combined laminin and HA gels are further stabilized by cross-linking to the desired extent, in order to promote or retard biodegradability, to increase or limit the porosity of the gel, to promote suitable hydrodynamic 10 characteristics, and to achieve other desirable properties as required for the clinical utility of these gels either alone, or in conjunction with medical implants or devices.

Methods of using these gels *in vivo* in clinical applications are disclosed. The gel matrices according to the present invention may be used clinically for a 15 variety of protocols, whether *per se*, or as a cell-bearing implant, or as a coating for a medical device or scaffold. The gels themselves even when devoid of cells may serve as a vehicle to support cell growth *in vivo* and as a depot to transport various bioactive high molecular weight substances including but not limited to growth factors, growth inhibitors, adhesive molecules, adhesion inhibitors, and the 20 like or small molecular weight drugs.

The gel matrices according to the present invention may advantageously be used as a substrate suitable for supporting cell selection, cell growth, cell propagation and differentiation *in vitro* as well as *in vivo*.

The present invention provides novel compositions and processes for the

production of these compositions. Advantageously, during the production of the compositions it is possible to control the viscosity and the degree of elasticity or malleability of the product, as well as other properties of clinical significance including but not limited to biodegradability, porosity and other attributes.

5 The degree of cross-linking is controlled by selection of a cross-linking agent, by the concentration of the cross linking agent, by the duration of exposure to the agent, by the temperature, and other parameters as are known in the art. Suitable cross-linking reagents include but are not limited to various sugars, enzymatic means, and chemical cross-linking agents including formaldehyde, 10 glutaraldehyde, and other agents as are known in the art. The use of sugars is currently a most preferred embodiment, inasmuch as these cross-linking agents are generally non-toxic. The physiological levels of sugars present in tissue culture medium may suffice to effect cross-linking though at a very slow rate compared to that achieved by the addition of super-physiological levels of sugars.

15 The gel matrices according to the invention comprise hyaluronic acid in the range of about 0.05% to about 5% (w/v) and laminin in the range of about 0.005% to 0.5% (w/v). More preferable ranges of hyaluronic acid are from about 0.2 to about 3%. Most preferably hyaluronic acid comprises about 0.5 to 2% of the gels. More preferable ranges of laminin are 0.05% to 0.2%.

20 Viscosity of the gel matrices in accordance with the intended utility may range from 4 to 48 centipoise. Currently most preferred viscosities range from 20 to 25 centipoise.

The present invention also provides for the addition of further active ingredients to matrices comprising hyaluronic acid and laminin, including but not

limited to hormones, growth factors, growth inhibitors, adhesion factors, adhesion inhibitors, anti-fibrotic agents, agents that prevent restenosis, anti-coagulants, coagulation promoting agents, anti-inflammatory agents and the like. These optional additives may be incorporated in such a manner to provide for desired 5 pharmacokinetic profiles. Within the scope of the present invention there are provided methods of using the HA-LN gels for sustained release of bioactive components in vivo. In other instances the additives may be incorporated in such a manner to provide for short-lived optimal local concentrations of the bioactive molecules incorporated therein.

10 The compositions of the invention may further comprise additional macromolecular structural components including but not limited to additional extracellular matrix components, or natural or synthetic polymers, as are well known in the art. According to certain preferred embodiments it is possible to include synthetic or natural polymers in the form of a plurality of carriers 15 dispersed within the gel. According to other preferred embodiments it is possible to use polymers as a mesh or scaffold within the gel.

The compositions of the invention may further comprise additives including preservatives, antimicrobials, isotonicity agents, buffering agents and the like as are well known in the art.

20 The physico-chemical parameters of the gel matrix, including but not limited to the physical mechanical properties of these gels may readily be optimized in accordance with the intended use of the gel, and methods are disclosed to provide guidance to the skilled artisan in optimization. The biological parameters of the gels may also be controlled including the cell bearing capacity

or cell load of the product. Currently most preferred embodiments comprise cell densities ranging from 10^5 to 10^7 cells per ml. of the gel.

Devices comprising the gels of the present invention are disclosed as well as uses of such devices.

5 According to one particularly preferred embodiment, coronary stents coated with the gels of the invention are provided. The gel adapted for coating these devices may further comprise cells. The devices coated with the gels of the invention may further comprise drugs, including but not limited to growth modulators such as growth inhibitory agents, growth factors or hormones
10 including but not limited to drugs that prevent or diminish restenosis.

Brief Description of the Figures

FIGURE 1 Schematically represents an exemplary stent (1) coated in an HA-LN gel according to the present invention. The gel (2) forms a tube or sleeve surrounding the stent (1) embedded within. The gel may have an exterior portion with higher viscosity as an exposed surface (3) and an interior surface (4), surrounding an open lumen (5), which forms upon expansion of the stent. The gel coated stent is expandable either by a balloon that is placed within the crimped lumen or by other means such as Nitinol (nickel-titanium) shape memory alloy.

20 FIGURE 2 A schematic representation of a scaffold (1) for implantation within the spinal column comprising gel (2) with embedded polymer or metal mesh (3), having a cylindrical shape with an internal open lumen (5). The cylinder may be perforated or pre-cut to open along one side (4) to enable wrapping it around the spinal cord for example.

FIGURE 3 Represents an explant of spinal cord from a rat embryo (E-14) grown for seven days in HA-LN gel. Figure 3A and 3B show culture on Cultisphere microcarriers (phase contrast microscopy). Figure 3C shows culture on DE-52 cylindrical microcarriers (silver staining).

5 **FIGURE 4** Shows single neurons isolated from spinal cord of rat embryo (E-14) ten days in culture in HA-LN gels ([phase contrast microscopy]).

10 **FIGURE 5** Depicts A- a single neuron grown in HA-LN for two weeks (Silver staining); B-Myelinated fibers (arrows) in an explant of spinal cord grown for three weeks on DE-53 cylindrical microcarriers in HA-LN gel (phase contrast microscopy).

FIGURE 6 Scanning electron microscopy (SEM) of spinal cord neurons dissociated from E-14 rat embryo, grown for two weeks on DE-53 cylindrical microcarriers in HA-LN gels.

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Detailed Description of the Preferred Embodiments

It is now disclosed according to the principles of the present invention that cross-linked gels comprising hyaluronic acid combined with laminin have unique attributes that make them suitable for a very wide variety of cell types as well as 20 for use as implants or for coating medical devices intended for implantation into a human subject. The gels of the invention may be adapted for use either with or without cells, for injection, for filling a cavity or for coating a medical device or scaffold, and for many other applications either in vivo or in vitro. It is explicitly understood that the gels are suitable for the culture of cells in a three dimensional

manner at varying cell densities.

The unique advantages of the present gels over many other matrices known in the art include their ability to support cell growth, particularly of cell types for which satisfactory growth is not readily achieved, as exemplified for 5 neural cell types, as a non-limitative example. Importantly, the gels of the present invention lend themselves to differential support of cell types, so that it is possible to maintain or propagate the desired cell types while suppressing undesired cell types. This property may be enhanced by specific additives, selected for their known ability promote or suppress cell growth in a cell lineage specific manner.

10 These additives include growth factors, hormones, growth modulators, and drugs.

The gels of the present invention will be cross-linked, preferably by the use of sugars, or enzymes though the desired extent of cross-linking may be accomplished by any means known in the art. The additives that are to be incorporated into the gel matrix may also be cross-linked to the gel components or 15 otherwise entrapped, to control their release at an appropriate rate. Thus the release of agents incorporated into the gels may be controlled, as well as the biodegradation of the whole implant or gel coating.

A) Development of the HA-LN gel for neuronal cell types.

20 The extracellular matrix (ECM) components of tissues have an important role in directing and regulating the cellular activities. In order to simulate the ECM environment for neuronal and glial cultures the current described procedures were first developed.

The methodologies for the maintenance, growth and differentiation of

neuronal cultures are known to be most sophisticated. Therefore, an ECM milieu which mimics the *in vivo* substrate and requirements of neuronal cells is most desirable. Therefore, an ECM milieu which mimics the *in vivo* situation of neuronal cells is most desirable.

5 Tissue culture methods have gained attention as a substitute for the use of *in vivo* animal models. One direction was devoted to the creation and simulation *in vitro* of the *in vivo* environment, nature and composition of the extracellular matrix (ECM) for the cultured cells or explants. It is now disclosed that based on a thorough review of the role of ECM substances in the development of the nervous
10 system, two major components, namely Hyaluronic acid (HA) and Laminin (LN), have emerged as essential candidates specially for neuronal and glial cell cultures.

The combination of HA and LN into one viscous adhesive gel (HA-LN gel) has provided a biomatrix for growing neuronal cells and explants the derived from both the central and the peripheral nervous systems. The combination of HA
15 and LN, which are major components of the ECM have been introduced by the inventors as substrates for growing neuronal cells and explants derived from both the central and peripheral nervous systems.

It is now disclosed for the first time that in addition to providing a substrate matrix *in vitro*, the HA-LN gel serves as a highly advantageous
20 biocompatible delivery vehicle for implantation.

B) Development of HA-LN Gels for Additional Cell Types

It is now disclosed for the first time that the in addition to providing a matrix well suited for neuronal cell types the gels of the invention are highly

suitable for a wide variety of cell types. As will be exemplified hereinbelow, these gels overcome many drawbacks of existing cell culture technologies.

In addition to neural and endothelial cells the HA-LN gel provides an appropriate substrate for growing primary and secondary cultures of tissue 5 explants and cells, as well as for established cell lines and transformed or bioengineered cells in culture.

Thus, by way of example, these gels have now been found to be adapted to the purpose of cultures of endothelial cell types, epithelial cell types, bone marrow 10 stem cells, embryonic stem cells, progenitor cells derived from embryonic stem cells, beta cells, chondrocytes, and many other cell types for which it has proven difficult to obtain a suitable milieu.

C) Development of HA-LN Gels for coating medical devices

Due to the advantageous properties of the gels it is now disclosed that 15 these gels are particularly useful to coat medical devices thereby improving the biocompatibility of a variety of medical implants whether inert or cell bearing.

According to one currently more preferred embodiment, the gels of the invention are used to coat a stent, either with or without cells. It has now been found that the gels used to coat stents may further advantageously serve as a 20 milieu comprising endothelial cells. These endothelial cells may suppress or diminish restenosis, which often occurs following the placement of the stent. The endothelial cells may be obtained from human umbilical cord or other compatible sources, including but not limited to human embryonic stem cells. A unique advantage of the gels of the invention for this purpose is that they are flexible,

pliable and elastic and may be distended in order to allow the deployment of the stent at the desired vascular site.

Gel can be applied in various ways, directly on the stent, or as an elastic, expandable tube covering the stent device scaffold, as shown schematically in

5 Figure 1. Viscosity of the gel can be uniform or can vary from the internal side of the tube to its external side that will be in contact with the blood vessels. The gel and any carrier materials encasing the stent scaffold can be made to have various porosities, as well as different biodegradation rates. These two features allow a controlled release rate of bioactive compounds or other additives from within the 10 gel matrices. The release rate may be at a slow steady rate, or in certain circumstances it may be designed to produce an initial burst release.

Drug eluting polymer coatings for stents have been reported (e.g., Tao Peng et al., 1996; EP-701802) which teach polymer stents that can incorporate or bind drugs for later local controlled delivery at the target site that would inhibit 15 thrombus formation and neointimal proliferation. Local administration of various drugs including urokinase, heparin, taxol, and hirudin peptide have been proposed to prevent thrombosis and restenosis.

The gel by itself, or when coated on a scaffold of a vascular stent or in other applications, can serve as a physical buffer having advantageous properties. 20 For example the gel as a coating on the stent may provide a physical buffer that will prevent damage to the endothelial surface of the blood vessel upon placement of the stent.

D) Detailed Features of the ECM-Gel Components:**1) HYALURONIC ACID (HA):**

HA was introduced as a viscous growth permissive milieu (Robinson et. al. 1990). It is a natural occurring high molecular weight polymer ($2.5\text{--}3.0 \times 10^6$ Dalton) which belongs to the glycosaminoglycan family. Compound of this family are composed of repeating units of uronic acid (glucuronic acid) and N-acetyl hexosamine (N-acetylglucosamine). In a hydrophilic environment, HA imbibes large amounts of water molecules (Laurent 1964; Ruohslahti 1988; Preston et. al. 1965). Under these conditions HA is forming hydrated gels of a manipulated viscosity dependency. These gels are serving *in vivo* as a space filling substance (Longaker et. al. 1989). During the early developmental stages of a fetus, HA is a major component of the ECM, which is considered an optimal environment for repair regeneration and wound healing. Later in life HA is found in joints, synovial fluids, in the genital tract and in other tissue matrices, such as cartilage and the nervous system (Gahwiler 1984; Yasuhara et. al. 1994). HA is the ligand of many cell surface receptors and cell membrane proteins (Knudson and Knudson 1993). Further advantages related to HA *in vivo* are: a non-antigenic substance, humidity holder, elastic rheological lubricant, antiangiogenic agent, and an antioxidant (Balazs and Denlinger 1988; Toole 1982).

In vitro, HA serves as a growing milieu, traps ions, cells and growth factors and helps cell motility, as disclosed for example by one of the present inventors in Israeli Patent 91080. In addition, it has been reported to modulate neuronal migration and neurite outgrowth (Kapfhammer and Schwab 1992;

Thomas et. al. 1993). HA is a biodegradable molecule sensitive to degrading enzymes, such as hyaluronidases and chondroitinases.

2) LAMININ (LN):

5 The LN are well defined family of glycoproteins that provide an integral part of the structural and functional scaffolding of almost every mammalian tissue, e.g. basement membranes conveying messages to cells. The LN is an adhesive glycoprotein-ligand composed of three sub-units with a molecular weight of 900,000 Daltons. Laminins possess the RGDS (Arg-Gly-Asp-Ser) 10 sequence recognized by the transmembranal structure of the most common integrin ($\alpha_5\beta_1$). LN-integrin is known as a major cell-matrix binding structure. Each LN is a heterotrimer assembled from alpha, beta and gamma chain subunits, secreted and incorporated into cell-associated extra-cellular matrices. The different types of LN (currently there are 12 known types) can self-assemble, bind 15 to other matrix macromolecules, and/or interact with cells via integrin receptors, dystroglycan or any other even non-integrin receptors. LNs critically contribute to cell differentiation, cell growth, cell shape, migration and movement, preservation of cell-tissue phenotype and elongate tissue survival. The different LNs have been found to be involved in coordinating and guiding many developmental roles in 20 diverse cell types and cell migration toward their final sites during organogenesis (Colognato & Yurchenko, 2000). To date, twelve isoforms of LN have been identified assembled from a repertoire of five alpha chains, three beta chains and two gamma chains (Miner & Patton, 1999). A better understanding of the LNs could provide a basis of therapy to several major pathologies, e.g. merosin-

deficient congenital muscular dystrophy.

In summation the LNs display a remarkable repertoire of functions, most importantly as structural elements. Furthermore the LNs serve as signaling molecules providing the cells with diverse information by interacting with cell surface components belonging to the adhesive molecules such as the integrins, connecting the cytoskeleton and the cellular biosynthetic machinery of cells. In developing migrating neurons recently a new cell adhesion molecule designated gicerin was discovered which displays binding activity to neurite outgrowth factor (NOF), which belongs to the LN family (Tairu, 1999). Gicerin promotes neurite extension during embryonic development and participates in the formation and histogenesis of neural tissue later in life. Gicerin is expressed during regeneration in other tissue than the nervous system as well (Tairu, 1999).

LNs are potent stimulators of neurite adhesion and outgrowth *in vitro*, reflecting an *in vivo* role in acceleration of axon outgrowth (Powell & Kleinman, 1997).

LN has proven to be an influential glycoprotein of the ECM, which guides and promotes the differentiation and growth of neurons and growth cone behavior (Luckenbill & Edds, 1997). Changes of cell surface integrin expression regulate as well neuronal adhesion and neurite outgrowth (Condic & Letourneau, 1997). Neuronal LN receptors play as well a key role in neuronal outgrowth (Edgar, 1989; Mecham, 1991). Manipulations of the LNs and LN receptors activity can be obtained by using antibodies against the ligands (laminins) or their receptors which finally determine axonal regeneration (Ivins et. al., 1998), or the neurite outgrowth domain of LN (Liesi et al., 1992). A motor neuron-selective adhesion

site on LN receptor acts to inhibit neurite outgrowth (Hunter et al., 1991).

E) Features of the Gel

It appears that the combination of HA and LN provides both a flexible,
5 elastic bonding and a tight, rigid bonding of cell-matrix.

It is clearly understood according to the principles of the invention that
any HA and any LN may be used to prepare the gels of the invention. Hyaluronic
acid may be used in its native form, as an uncrosslinked form, or as one of the
many chemically modified hyaluronic acid derivatives that are known in the art
10 including but not limited to cross-linked hyaluronans.

Further chemical treatments of the gel mixtures include cross-linking by
sugars or additional cross-linking agents or adhesive substances. For instance, by
way of a non-limitative example, according to one currently preferred
embodiment a solution of sugars including but not limited to one percent D-
15 ribose, D-xylose or any other sugar may be incubated for approximately 24 hrs. in
the cold (4°C) with the gels. The uncoupled sugars are rinsed off the gel prior to
use. Small amounts of albumin 0.01-0.1% may be optionally added for improving
the gel features, providing additional groups participating in cross-linking..

While it is possible to use other cross-linking agents or enzymatic
20 processes (by way of non-limitative example including factor 13 or lysyl oxidase)
to obtain the cross-linked gels, the use of sugars for cross-linking is particularly
advantageous due to the non-toxic nature of these naturally occurring agents. The
non-toxic nature of the cross-linking agents, and the resultant increase in the
molecular weight of the product, stabilizes the gel, and improves the end product.

Cross-linking also serves as a means for converting the gels to a reservoir or depot of additives including high molecular weight cell adhesion molecules, cell growth factors and any other suitable additives. These biomatrix products are viscous, adhesive, highly hydrated formulations simulating the natural 5 extracellular environment and therefore highly biocompatible and conducive for cell growth. Optimization of the matrices includes selection of process parameters to include suitable ranges of the two main components. The composition will affect the rigidity or viscosity of the resultant mixture obtained. Rigid gels may be more suitable for implanting as a molded or shaped implant within an aperture to 10 be filled, while other clinical applications will require the introduction of the matrix as a less rigid, i.e., more fluid or elastic, moldable implant or coating.

Importantly, further ingredients may be used to alter the intrinsic properties of the essential components. By way of a non-limitative example, it may be advantageous to include particulate carriers to which cells may adhere 15 within the gel matrix.

It is now disclosed that it is advantageous to cross-link various groups of the matrix components. The simplest kind of cross-linking bonds are created by sugars including monosaccharides, such as hexoses or pentoses, which bind to free amino groups. Enzymatic bonding of monoamine oxidases (e.g., Factor X111 20 and lysyl oxidase) creates free aldehydes from free amino groups. These aldehydes, as well as the sugar aldehydes like the reducing end of carbohydrates, e.g., hyaluronic acid, can create an aldol condensation and a Schiff-base product covalently cross-linked. Thus each HA can create one bond with its reducing end residue and many interactions with the hydroxyl groups. Free aldehydes and free

amino groups can further react and form crosslinked bonds.

One major attribute of the HA-LN gels is the ability to formulate gels of a desired viscosity or rigidity depending on the concentration of HA and LN as well as the use of cross linking agents and the like.

5 The gel matrices according to the invention comprise hyaluronic acid in the range of about 0.05% to about 5% (w/v) and laminin in the range of about 0.005% to about 0.5% (w/v). More preferable ranges of hyaluronic acid are from about 0.1% to 2%. The selection of the preferable ranges depends on the intended use.

10 More preferable ranges of laminin are from about 0.05% to 0.2%. The selection of the preferable ranges depends on the intended use.

Viscosity of the gel matrices in accordance with the intended utility may range from 4 to 48 centipoise.

15 In one currently exemplified preferred embodiment the combined gel comprises 1% hyaluronic acid (as sodium hyaluronate) and 0.01% laminin.

F) Gel Formulation

The HA-LN gel was developed as a substrate for culturing neuronal-glial cells for implantation. Further extensions and improvements of the HALN-gel for 20 both *in vitro* and *in vivo* usages of stimulating neuronal outgrowth are now disclosed along the following lines: The hyaluronic acid (HA) component will be examined as to its optimal molecular weight, concentration, viscosity and possible modifications of the active groups (e.g., hydroxyl to benzyl or other substituent groups as are known in the art).

The second component laminin (LN) may be any one of the twelve types of laminin. According to one currently preferred embodiment laminin-1 is conveniently used. This type of laminin may be replaced with isolated fragments of laminin or laminin derived peptides which retain the desired biological activity 5 as substrate for cell binding. Furthermore, cross-linking between the two components will be induced by any suitable means as are known in the art, preferably using sugar molecules. The interacting outcome will be confirmed by any suitable means as are known in the art including but not limited to crystallographic analysis.

10 Furthermore, enrichment of the HA-LN gel by additional bioactive molecules is encompassed within the scope of the present invention. Examples of such bioactive components include other extra-cellular matrix (ECM) components (e.g. fibronectin, collagen or the like), adhesive molecules (e.g. integrins including but not limited to nidogen, CD-44, gicerin, dystroglycan, etc.), growth factors 15 (e.g. IGF-I, bFGF, EGF, BDNF, PDGF, NGF etc.), hormones (e.g. estrogen, testosterone etc.), gluing elements (e.g. fibrin or fibrinogen, thrombin, etc.) antioxidants and enzymes to solubilize scar tissue after operations performed in the peripheral nervous system (PNS) and central nervous system (CNS). Non-limitative examples of such enzymes include, but are not limited to trypsin, papain 20 or proteases of plant origin etc.)..

The formulation of the gel is highly variable composing specific mixtures creating a spectrum of gels to adjust to the use of a variety of cell type cultures, various tissue implants and various ways of applications for a variety of functions.

G) Optimization Procedures

Specific combinations of gel components have been developed for the following variety of purposes:

Optimal gel for growing neuronal tissue in vitro.

5 Milieu for embedding neuronal composite implants grown on appropriate scaffolds (e.g. pre-treated embryonic spleen tissue used as scaffold for neuronal cells) for transplantation into injured sites of brain and spinal cord tissue.

10 The use of a HA-LN gel as an implant intended for use as a sheath for guided tissue regeneration in the spinal cord is depicted schematically in Figure 2.

15 Using neuronal cells embedded in HALN-gel for filling (either by surgical intervention or also by injection) post-traumatic or post-operative cysts resulting for example from injury, hematomas, or tumor removal.

20 Combining the HALN-gel with additional factors including but not limited to: coagulative factors, anti-fibrotic agents, growth factors, or proteolytic enzymes which might lead respectively to promotion of hemostasis, the solubilization of scar tissue, and enhancing axonal regeneration.

25 Use of the HA-LN gel matrices for use in conjunction with embryonal stem cells to be selected for differentiation into the cell type of choice.

It must be stressed that gels, according to one currently most preferred embodiment of the present invention, have been optimized for

use in conjunction with neural cell types, suitable for use in ameliorating deficits and defects in the central nervous system.

According to an alternative most preferred embodiment the gels are used in conjunction with medical devices in the vascular system in general 5 and the cardiovascular system in particular.

The skilled artisan will appreciate the general applicability of the methods disclosed herein. The availability of human cloned cell lines, pluripotent embryonic stem cells, autologous cells, bioengineered cells comprising inserted genes or antisense moieties and additional cell types 10 will lend themselves to use with the methods and compositions of the present invention. Thus, for the sake of example, human embryonic stem cells may be selected or activated to differentiate into any desired cell type suitable for transplantation utilizing the gel matrices of the present invention.

15

H) The Preferred Uses of the Product

The HALN-gel product can be used for the following purposes:

1) Tissue Culture:

An adhesive biological environment which provides an optimal milieu for 20 the anchorage of cells and tissue slices during cultivation.

The product serves as a reservoir for desired pharmacokinetics of growth factors, hormones, signal molecules, inhibitors of cell growth and any other type of cell growth modulators.

In addition the gel enables absorption of nutritional elements and provides

mechanical and biochemical protection of the cultured cells, as well as enabling neutralization of damaging cellular metabolites such as free radicals or the like.

2) Delivery Vehicle for Transplantation:

5 The product serves as a delivery vehicle for transplantation of implants.

The implants may be devoid of viable cells or may be loaded with cells according to the intended medical indication being treated.

For use in the central nervous system the transplants will preferably be cell-bearing, while for use in bone or cartilage repair they may be used preferably 10 without cells.

The gel product serves as a storage depot for pharmacological, enzymatic and other agents and drugs such as inhibitors of neurological scar, promoters of neuronal growth, immunosuppressors, chemotherapeutic agents, anti-adhesion agents, anti-fibrotic agents, and other cell growth modulators as required

15

3) Coating of a medical device:

Gel can be applied in various ways, directly on the medical device as a coating for an external surface, or for coating an aperture or lumen in the device, or as an elastic, expandable tube covering the device which serves as a scaffold.

20 Viscosity of the gel can be uniform or can vary from the internal side of the coating to its external side that will be in contact with the tissues into which the device is implanted. The gel and the carrying scaffold material can be made to have various porosities, as well as different biodegradation rates.

I) Routes for Clinical Applications of the Gel

- a) By injection of the product into affected area, filling in cavities, cysts, etc.
- b) Covering resurfacing affected areas with the product functioning as a 5 biological glue.
- c) Placing the product within tubes or capsules which will fill the gaps respectively, in nerve reconnection and transplantation into the central nervous system.

C) Placing the product within or as a coating on the exposed surfaces of 10 stents, for vascular uses and angioplasty, respectively, especially for cardiovascular applications.

J) Indications for Neural Clinical Applications of the Product**(HALN-gel)**

- 15 a) Peripheral nerve, spinal cord and brain injuries and damage.
- b) Spinal cord, brain peripheral nerve reconstruction/transplantation.
- c) Tissue and drug administration in brain degenerative and demyelinative diseases (Alzheimer, Parkinson's disease, Multiple Sclerosis, etc.).
- d) Post-operative or post-traumatic brain or spinal cord cysts.
- 20 e) Prevention or decreasing of post-injury or post-surgical scarring.
- f) Spinal form of multiple sclerosis.

All the above mention utilization of HALN-gel in neuronal cultures and implantation are adjustable to other tissue types for treatment of a wide

variety of injuries or disorders. Suitable cell or tissue types for use in conjunction with the matrices of the present invention include but are not limited to endothelial cells, liver, cartilage, bone, heart, spleen, lung, skin and blood vessels.

5

The following examples of certain currently preferred embodiments are provided merely for illustrative purposes and are not to be construed as limitative. The scope of the invention is defined by the claims which follow.

10 Examples

Materials

The HA component was provided by BioTechnology General LTD (Rehovot, Israel). It was examined as to its optimal molecular weight, concentration, viscosity and possible modifications of the active groups (e.g. 15 hydroxyl to benzyl).

The detailed composition of the HA used contained: 90% sodium hyaluronate; molecular weight (mega Daltons) - 2.01; protein (mg/g) - 0.2; absorbance at 257nm (1% solution) - 0.02; endotoxin (1% solution) (EU/mg) - <0.125; (non-inflammatory substances).

20 1. The HA-gel has a viscosity of dynamic intrinsic viscosity as may be measured by streaming a solution in a capillary of a viscometer at 25°C and expressed as μ viscosity coefficient in centipoise ranging between 8 to 48 depending on the molecular weight that can range between 2 to 8×10^6 Daltons. (Bag's HA ranges 2.5 to 3×10^6 Daltons).

The second component LN is tested and compared with different laminin peptides around the active sites, for biological activities. The best characterized LN is LN-1 (composed of 1 alpha, 1 beta and 1 gamma), it promotes neuronal outgrowth in all developmental stages in embryonal and adult neurons. It is 5 believed that LN-1 is a guiding substrate for axons in vivo.

Murine LN-1 used in our experiments was obtained from Sigma.

Furthermore, cross-linking between the two components is induced, preferably using sugar molecules. The interacting outcome is confirmed by any appropriate means including crystallographic analysis.

10 The formulation of the gel is highly variable composing of specific mixtures creating a spectrum of gels in regards to their composition, physical and biological features. The various gels are adjusted to the use of a variety of cell type cultures, various tissue implants and various intended applications for a variety of functions.

15

A. Optimization Procedures

Specific combinations of gel components have been developed for the following variety of purposes:

1. Optimal gel for growing neuronal tissue in vitro:

20 The center area of 35 mm plastic dishes is coated by HA-LN-gel prepared as follows:

A volume of 0.3ml HA from a 1% solution is diluted with 0.6ml of Hank's Balance Salt Solution, containing 100 micrograms of LN. This volume of 0.9ml HA-LN mixture is sufficient for coating nine 35mm plastic dishes (100

microliter/dish containing 12 micrograms of LN). The HALN coated dishes are left for 1hr. and an amount of 600 microliters per dish of nutrient medium is added, sufficient to cover the coated area with a thin fluid layer.

Cross-linking will be performed with any suitable cross-linking agent, 5 preferably a sugar, for the appropriate length of time and at the appropriate concentration in order to achieve the desired degree of rigidity, porosity, biodegradability, etc.

Tissue explants (about 5-6 /dish) or dissociated nerve cell aggregates, previously suspended on microcarriers (MCs) were added to the viscous substrate 10 gel matrix and became firmly attached and covered by the gel. During the following days intensive sprouting together with cell migration and new outgrowth is taking place to form a dense network of neuronal and glial cells.

2. Milieu for embedding neuronal composite implants grown on appropriate scaffolds: neuronal tissue slices (300 micron thick) or dissociated 15 neuronal cells, as well as, embryonic stem cells are attached to positively charge microcarriers and growing suspension for 3-4 days. Prior to their transfer either to stationary cultures or to composite implants the suspended explants or cell-MCs aggregates were embedded in HALN-gel for further cultivation or for transplantation into injured or affected area of brain and 20 spinal cord. Examples of these cultures are presented in Figures 3-6.

3. Using neuronal cells embedded in HA-LN-gel for filling post-traumatic or post-operative cysts or cavities resulting from injury, hematomas, or tumor removal.

a) Treatment Procedures for Spinal Cord:

This treatment procedure is used in cases of injury, damage, posttraumatic/post surgical cysts or congenital syringomyelia and also in cases of degenerative and demyelinative diseases of spinal cord.

The injection or implantation of HALN-gel is introduced by injection
5 or implantation using needle, endoscopic, stereotactic, navigator techniques, etc., or standard surgical approaches with myelotomy.

HA-L gel is injected or implanted within the cyst cavity or affected area with or without biological materials, such as CNS tissue, stem cells, Schwann cells, growth factors, etc. This procedure would have to be
10 accompanied by microscopic spinal cord untethering at the injury site and expansion duroplasty.

b) Treatment Procedures for Brain:

This treatment procedure is used in cases of injury, damage, posttraumatic/post surgical cysts, cavity, strokes from ischemic and
15 intraparenchymal hemorrhages and also in cases of degenerative (Parkinson's disease and etc.) and demyelinative (multiple sclerosis and amyotrophic lateral sclerosis, etc.) diseases.

The injection or implantation of HALN-gel is introduced by injection or implantation using needle, endoscopic, stereotactic, navigator techniques,
20 etc., or standard surgical approaches.

HALN-gel is injected or implanted within the cyst or cavity or affected area with or without biological materials, such as CNS tissue, stem cells, Schwann cells, growth factors, etc.

4. HA-LN gel is unique in offering the possibility of exposure of explants, neuronal and glial cells, drugs, factors etc., into brain and spinal cord affected area.

5 In addition, HA-LN gel is playing an important role is in the reconstruction of implants of oligodendrocytes and Schwann cells from fetal and adult origins. These implants, composed of cultured central and peripheral myelin forming cells, are intended for transplantation to cure neuronal disorders resulting in demyelinating effects.

10 5. In addition to the CNS the reconstruction of peripheral nerve presents a unique clinical entity on its own.

The peripheral nerve or brachial plexus or cauda equina are exposed and treated microsurgically by external and/or interfascicular neurolysis, or primary sutures, or nerve grafts, scaffolds or tubes. After completion of reconstruction, 15 the exposed peripheral nerve is covered by HALN-gel per se or tissue engineered an filled into tubes or scaffolds with or without biological materials, such as Schwann cells, growth factors, drugs, and the like.

The foregoing examples of certain currently preferred embodiments are 20 provided merely for illustrative purposes and are not to be construed as limitative. The scope of the invention is to be defined solely by the claims which follow.

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CLAIMS

1. A biocompatible matrix comprising hyaluronic acid and laminin cross-linked by an exogenous cross-linking agent to form a combined gel.
2. The matrix of claim 1 wherein the exogenous cross-linking agent is a sugar.
3. The matrix of claim 1 wherein the gel has a viscosity of 4-48 centipoise.
4. The matrix of claim 1 comprising 0.05 % to 5% of hyaluronic acid.
5. The matrix of claim 1 comprising 0.005 % to 0.5 % of laminin.
6. The matrix of claim 1 comprising laminin selected from the group consisting of laminin 1 through laminin 12, laminin fragments and laminin derived peptides, which retain the activity of intact laminin.
7. The matrix of claim 1 wherein the hyaluronic acid component is selected from an acid, a salt, a cross-linked hyaluronan.
8. The matrix of claim 1 further comprising a bioactive compound or drug selected from the group consisting of a hormone, a growth factor, a proteolytic enzyme, an anti-fibrotic agent, a chemotherapeutic anti-proliferative agent, a coagulative agent, an anti-coagulative agent, an immunomodulator, or a growth inhibitor.
9. The matrix of claim 1 further comprising a structural component selected from the group consisting of an extracellular matrix component, a natural polymer, a synthetic polymer, or a mixture thereof.
10. The matrix of claim 9 wherein at least one polymer component forms a plurality of carriers within the combined hyaluronic acid laminin gel.

11. A cell culture comprising a plurality of cells cultured in or on a matrix comprising hyaluronic acid and laminin cross-linked to form a combined gel.
12. The cell culture of claim 11 where the cells are cultured on a plurality of carriers within a combined hyaluronic acid laminin gel.
5
13. The cell culture of claim 11 comprising a plurality of cell types.
14. The cell culture of claim 11 comprising a cloned cell type.
15. The cell culture of claim 11 comprising a bioengineered type.
16. The cell culture of claim 11 comprising an embryonic stem cell type
10
17. The cell culture of claim 11 comprising an autologous cell type.
18. An implant comprising a matrix according to claim 1.
19. An implant comprising a cell culture according to claim 11.
20. A method for preparing a biocompatible matrix to be implanted in a human subject, which comprises:
15
- hydrating a hyaluronic acid or salt or hyaluronan;
- selecting a laminin solution;
- cross-linking the hydrated hyaluronan and laminin to form a combined gel;
- optionally adding bioactive or structural components to the gel.
21. The method of preparing the biocompatible matrix of claim 20 which
20
- further comprises shaping the matrix.
22. The method of claim 20 which further comprises culturing or embedding cells in or on the gel.
23. The method of claim 22 wherein the cultured cells are adherent on a plurality of discrete carriers within the gel.

24. A kit for carrying out extemporaneously a method according to claim 20,
the kit comprising at least one dose of each constituent solution necessary
to obtain the gel which forms the biocompatible matrix.
25. A method for transplanting cells to an individual in need thereof,
5 comprising the step of transplanting an implant comprising cells in or on a
biocompatible matrix comprising hyaluronic acid and laminin cross-linked
to form a combined gel.
26. A medical device comprising the gel of claim 1.
27. A medical device comprising the cell culture of claim 11.
- 10 28. The medical device of claim 26 or 27 wherein the gel forms a coating on
the exposed surfaces of the device.
29. The medical device of claim 26 or 24 further comprising a bioactive
compound or drug.
30. The medical device of claim 23 or 27 wherein the device is a stent.
- 15 31. The medical device of claim 30 wherein the stent is an intracoronary stent.
32. The medical device of claim 31 wherein the viscosity of the gel varies
from the inner surface to the outer surface.

1/6

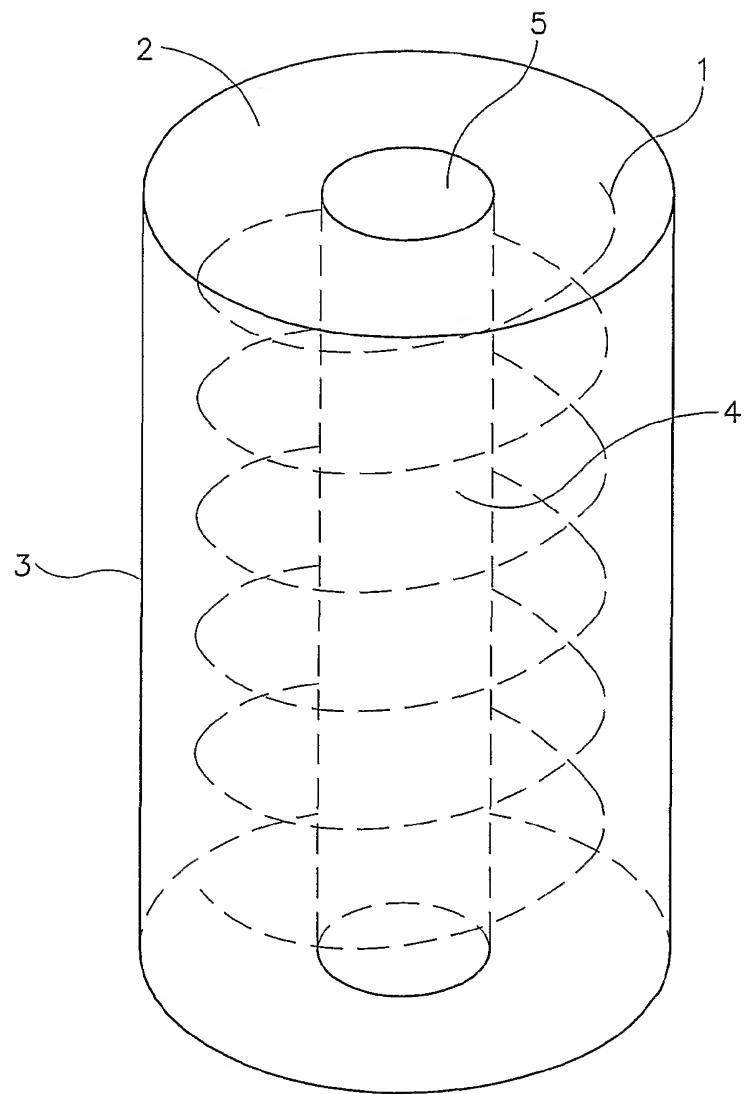


FIG.1

2/6

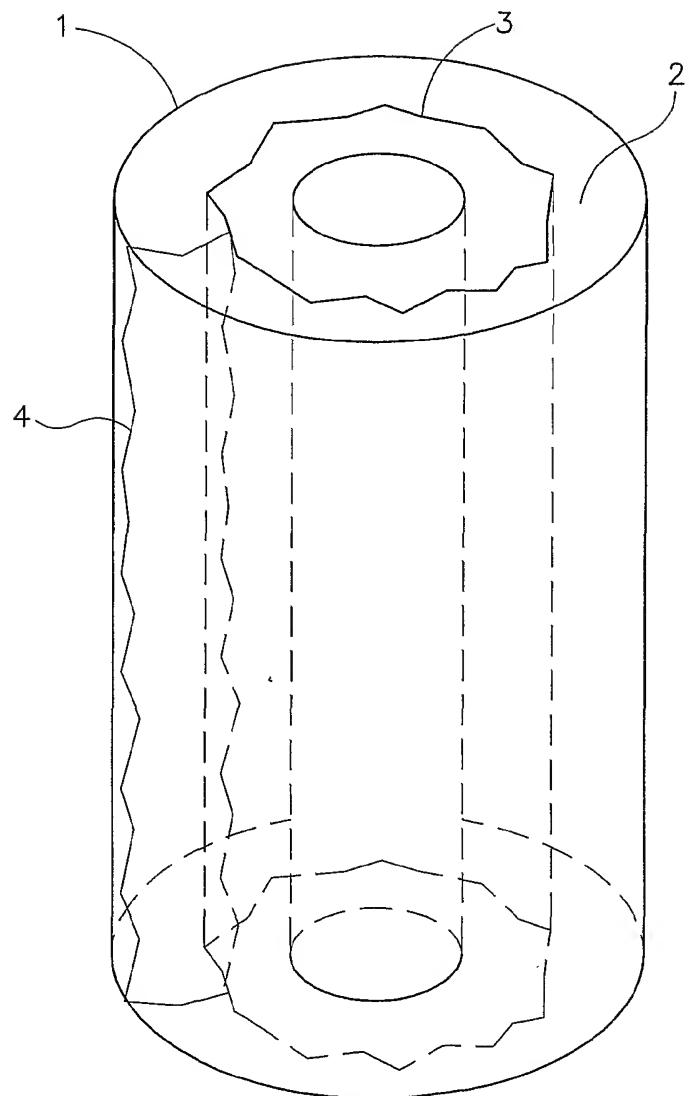
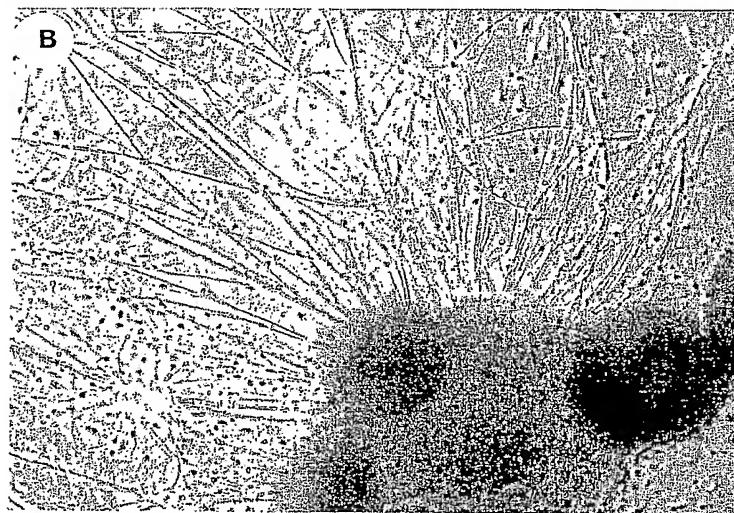
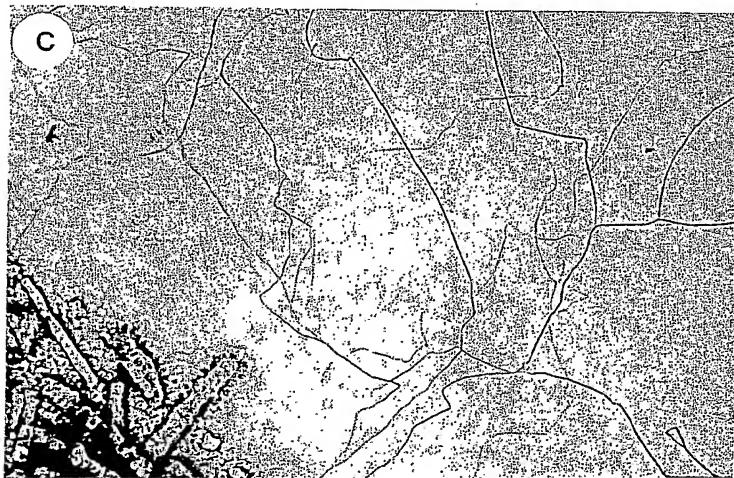
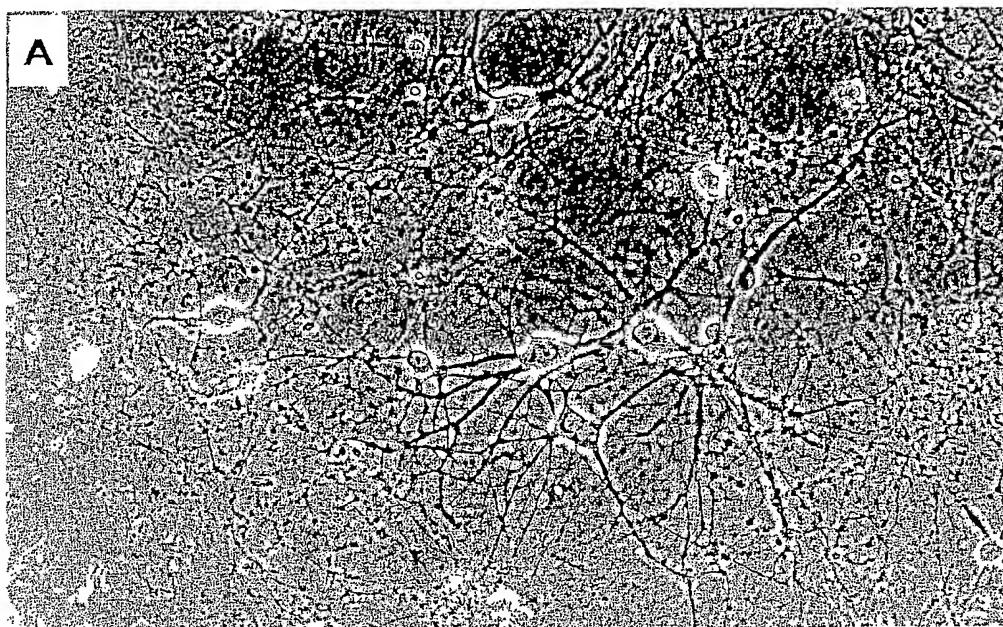
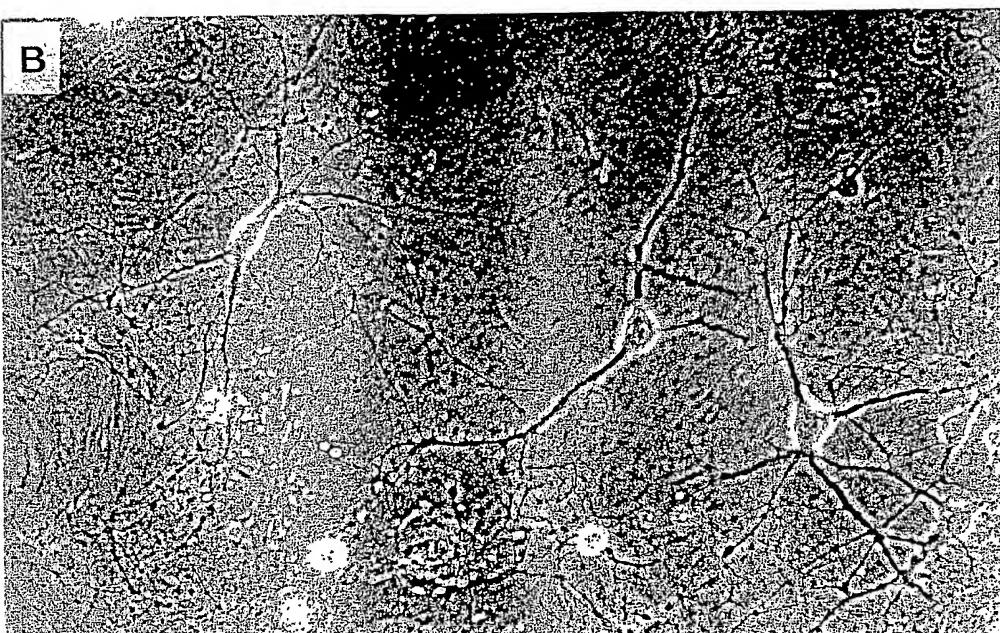


FIG.2

3/6

**FIG. 3A****FIG. 3B****FIG. 3C**

4/6

**FIG. 4A****FIG. 4B**

5/6

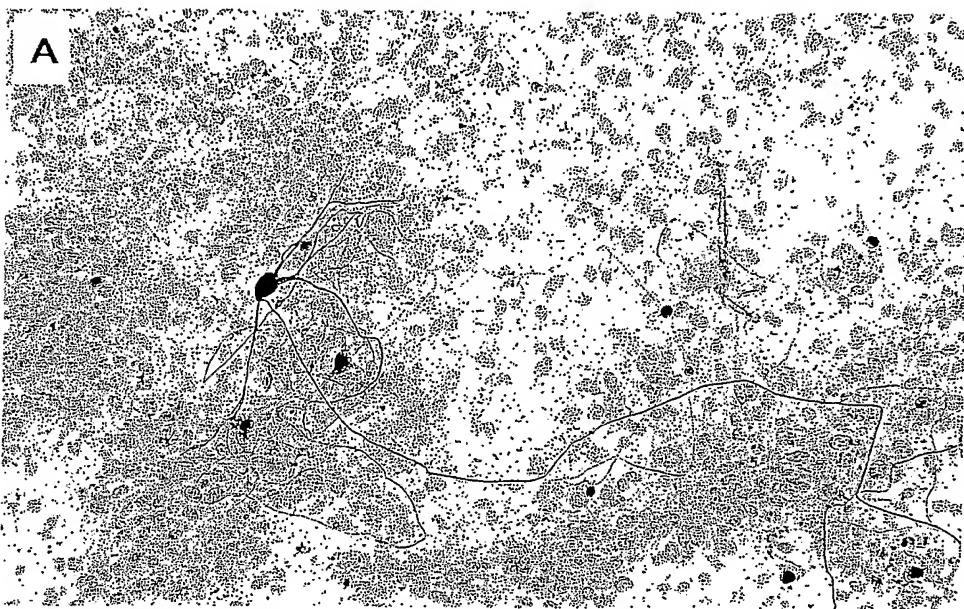


FIG. 5A

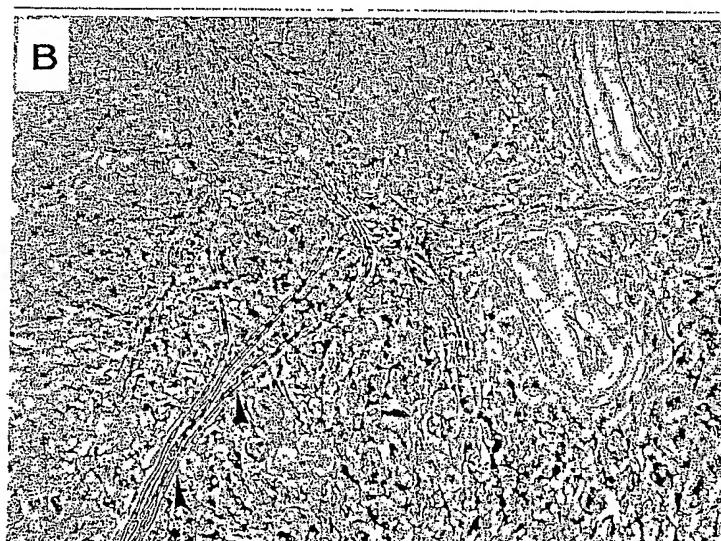
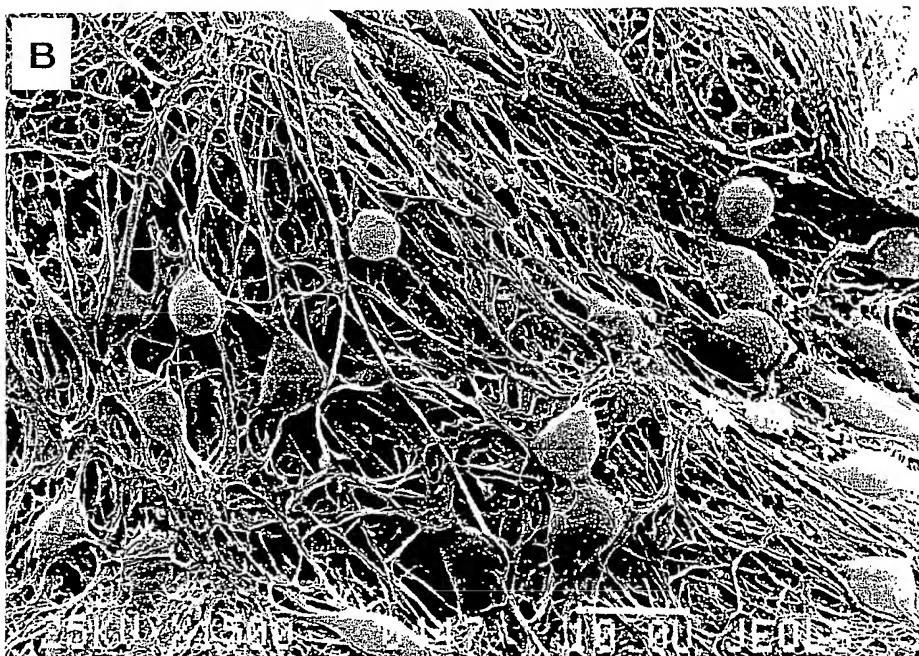


FIG. 5B

6/6

**FIG. 6A****FIG. 6B**